The Palomar Adaptive Optics System

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Abstract

Currently under construction at the Jet Propulsion Laboratory, the Palomar Adaptive Optics System (PALAO) is a Cassegrain-mounted system for infrared astronomy incorporating active laser metrology to minimize the effects of mechanical flexure.

System overview

The Jet Propulsion Laboratory began in 1995 the design and construction of an adaptive optics system for the 5 meter Hale Telescope at Palomar Mountain. This instrument will be mounted at the Cassegrain focus of the telescope and optimized for scientific use in the infrared (K, H, and J-bands). The PALAO system has at its heart a Xinetics 349 actuator deformable mirror (DM) and utilizes JPL-developed skipper CCD technology for the Shack-Hartmann-based wavefront sensor camera. The wavefront sensor (WFS) is based upon a 16 x 16 subaperture lenslet array, within which is inscribed a reduced image of the 5 meter telescope pupil. Initially natural guide star based, the system is designed to accommondate the future installation of a laser guide star subsystem without modification to the optical design.

The user interface for the PALAO control subsystem is resident on a Sun workstation that communicates externally with the telescope control computer and the science camera computer via the Palomar LAN. Internally, this host workstation communicates with a real-time VME control system that consists of a 68060 servo computer and 10 Texas Instruments C40 DSPs on 3 VME boards. The 68060 processor, running VxWorks, coordinates motor control and system telemetry signals, including video, as well as the wavefront controller high level functions, including loading reconstruction matrices and control loop filters onto the DSPs. The 10 TI C40 DSPs flat-field the WFS pixel data, calculate the WFS subarray centroid values, reconstruction the wavefront, and generate DM actuator commands, with a closed loop bandwidth of 500 Hz.

Optical configuration

The optical system is fundamentally a 1:1 relay, as shown in the layout as shown in Fig. 1. The optics are located on a custom Newport RS4000 optical bench which attaches horizontally and can rotate upon the Cassegrain ring of the Hale Telescope. A 45-degree fold mirror (FM1) diverts the F/15.7 Cass beam after focus to a collimating off-axis parabolic mirror (OAP1). An independent fast steering mirror (FSM) corrects global tip and tilt, while the deformable mirror), located conjugate to the primary, corrects higher order aberrations. Another fold mirror (FM2) reflects the light to meet packaging requirements although this mirror is also used for system alignment and DM calibration. A second OAP relays an F/15.7 beam through an output fold mirror (FM3) to the science camera (not shown). An advantage of this optical configuration is that the two off-axis parabolic mirrors have parallel parent axes and are in proximity on the optical bench which proves useful during alignment. Prior to FM3, an articulated dichroic mirror reflects the visible component of light through a second articulating mirror to the wavefront sensor field stop. Thus, science imagery is always on axis while the field steering mirror pair directs the guide star into the wavefront sensor (WFS). The WFS field stop is a reflective spot of nominally 2 arcsec diameter deposited upon an optical flat. After reflecting from the field stop the guide star light is recollimated and then passes through an atmospheric dispersion corrector (ADC). The WFS light then forms a pupil, conjugate to both the DM and primary mirror, inscribed within a 16 x 16 lenslet portion of the lenslet array (LA). The lenslet foci are demagnified onto the WFS CCD. Each subaperture is assigned a 4 x 4 pixel area from which a two-staged centroiding algorithm extracts subaperture tilt information with nearly quad-cell performance and increased dynamic range.

An acquisition camera resides beyond the WFS field stop, and views the stop and sky simultaneously, providing direct feedback during the guide star acquisition process. During operation, the field steering mirrors place the guide star onto the field stop. The guide star signal reaching the WFS CCD is used for fine adjustment before centroid offsets are recorded.

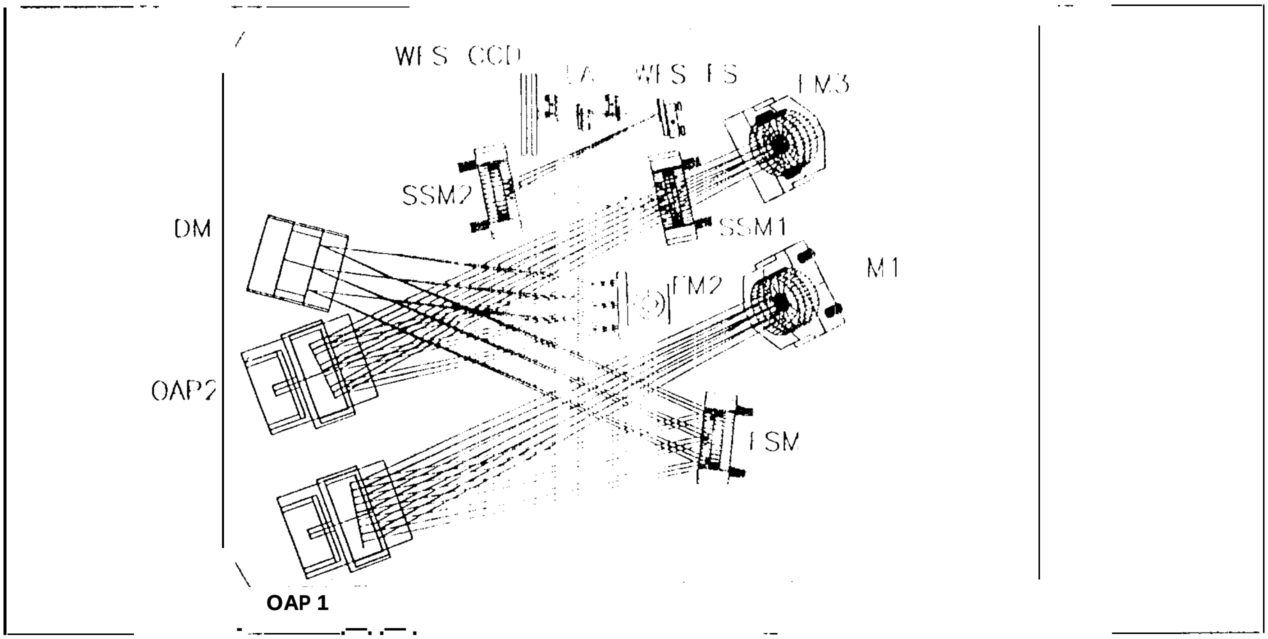

Figure 1. Optical layout of **PALAO relay.** A 45-degree fold mirror (FM1) diverts the f/15.-/ Cass beam after focus to a collimating off-axis parabolic mirror (OAP1). Next come an independent fast steering mirror (FSM), followed by the deformable mirror itself (DM). A fold mirror FM2 used for packaging the system in the existing cage which surrounds Cassegrain instrumentation. feeds a second OAP 1' which relays an F/15.7 beam through an output fold mirror (FM3) to the science camera (not shown)

Control system electronics

In addition to the computers described above, the PALAO control system utilizes several custom electronics boards resident in two VME chassis. The data room chassis contains the computers, the DM electronics interface board, and the WFS CCD interface board. A separate chassis resides in the Cass cage and is connected to the data room chassis via a VME bus extension. The Cass cage chassis houses 21 JPL-built DM high voltage driver boards, the DM interface board, a C40 image processing module, and IP module carrier boards that contain digital 1/0, A/D, D/A, and serial (RS-232) IP modules **used** to control approximately 30 computer controlled **elements,** including automated positioners, shutters, **sources,** flip-in mirrors, and lens wheels. A depiction of this **architecture is** given **in Fig.** 2.

Real-time wavefront control

The real-time wavefront controller consists of a combination of hardware and software components, which shall provide up to SO Hz closed-loop bandwidth control. The PALAO deformable mirror is a Xinetics continuous facesheet mirror utilizing poled PMN electrostrictive actuators. Of the 349 actuators, 241 are active controlled by PALAO, with the remainder slaved to the outermost active actuators. The Shack-Hartmann wavefront sensor is based upon a JPL-developed 64 x 64 pixel, 36 micron pitch, TE cooled CCD with 64 output amplifiers. Operated nominally at 500 Hz frame rates, this skipper technology chip and electronics allow multiple non-destructive reads in order to reduce centroid errors due to read noise. The goal of this detector development is < 5e- read noise from a single read and < 1 e- noise after multiple reads. Initial noise measurements **01** this chip are expected in April 1996. The DSPs can perform the reconstruction in 1.9 milliseconds. The average data age, from a 2 millisecond exposure, applied to the incident wavefront is 3.7 milliseconds.

Available to the operator as system telemetry are representations of the raw or flat-fielded pixels, the centroid values, the reconstructed wavefront and the DM actuator motions. The control system allows loading of new reconstruction matrices during closed-loop operation to account for changes in seeing conditions.

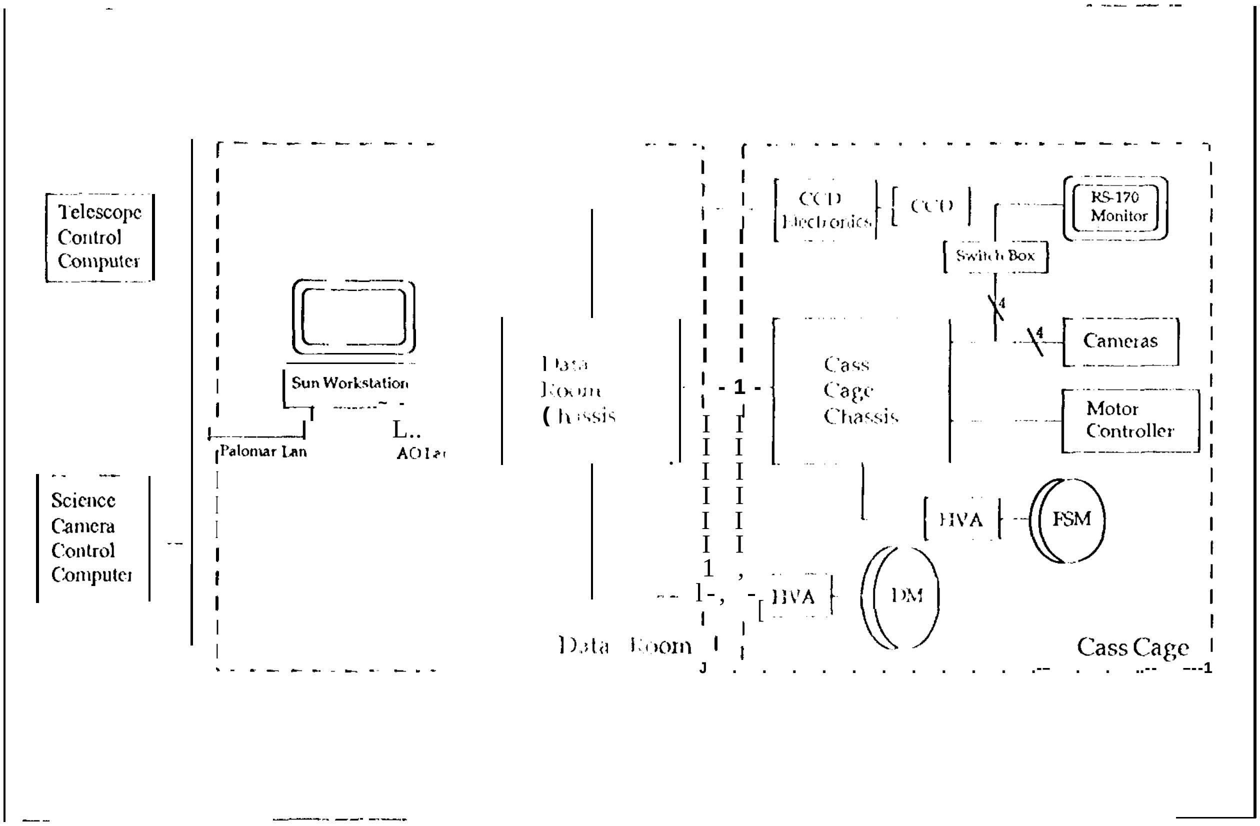

Figure 2. Hardware architecture for PAL AO control system. A host workstation communicates with the telescope drive controller, the science camera controller and a VME chassis in the data room connected via bus extension to a second VME chassis in the Cass cage.

Active metrology

Two laser metrology systems monitor the optics of the PAL AO relay and WFS. The first system is incorporated into an integrated stimulus, which additionally serves as a telescope and atmospheric seeing simulator. A phase-shifting interferometer within the stimulus will be used for initial system alignment and maintenance. Additionally, the stimulus laser source will allow sensing of the DM-to-WFS lenslet registration, as viewed by observing the WFS CCD signal in the presence of an applied DM actuator pattern. It is expected that this registration procedure will require less than 1 minute and is to be performed several times per night of observation. Physically, the stimulus occupies the volume within the space that attaches the AO instrument to the Cass ring.

The second metrology system, currently under design, will monitor non-common-path flexure between the WFS camera and the science camera. Non-common path flexure has proven to be a significant problem in operational telescope-mounted AO systems. In order to maintain image stability at the 10 milliarcsecond level over integrations as long as an hour, active metrology must be incorporated. The principle sources of these non-common-path errors are mount and table gravity flexure. We are currently considering several possible arrangements including a slit-viewing camera and several forms of laser metrology. Our final metrology design will be presented at the July meeting.

Acknowledgments

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